Sequential biological concentration: lessons learnt

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Introduction

There is an ongoing need to develop environmentally friendly and sustainable disposal methods for saline drainage water. The salinity drainage task force in California (San Joaquin Valley Drainage, 1990) developed several options to solve this problem. The solutions included: source control (Ayars 2003), reuse of drainage water (Ayars et al. 1993), in-situ use of ground water (Wallender et al. 1979; Ayars and Hutmacher 1994), land retirement, and evaporation ponds. These were all found to be effective; however, none of these could be used alone for complete disposal of saline drainage water. The concept of sequential biological concentration (SBC) integrates these concepts into a system that is capable of meeting the objective of drainage water disposal (Blackwell et al. 2004). The system is one of successive use of drainage water for irrigation of progressively more salt tolerant crops to concentrate the salt and reduce the total volume of water for disposal. The ultimate disposal of the very saline drainage water is by evaporation. One principle as stated by Jolly et al. (2000) that should be followed is "all productive uses have occurred or the water is shown to be economically unsuitable for use" prior to disposal in an evaporation facility.

The design of a SBC system requires subsurface drains with active controls, and it assumes effective collection of deep percolation water. The theory assumes that the successive use of water results in increased salt concentration in the deep percolate in proportion to the volume reduction of water by crop use. The optimum design of a SBC system will result in a minimum area of salt tolerant crops and a small evaporation facility. These components are the least viable economically and need to be minimized to insure that the total system is economically viable.

In California a system similar to SBC has been dubbed Integrated On-Farm Drainage Management (IFDM) (Ayars and Basinal 2005). An IFDM system was installed on a 260 ha site on the west side of the San Joaquin Valley (SJV) in 1995. This paper discusses the design and operation of this system, and highlights the effectiveness of this system in disposal of drainage water and characterizes some of the critical aspects of the design and operation of SBC systems.

Materials and methods

The IFDM system in California was composed of four 65 ha fields (Fig.1), each with subsurface drainage system installed at 1.8 m depth. A typical system is shown in Area B. The drainage system was piped to a pumped sump, which collected water and distributed it to the next reuse area. Three of the fields (A 9, A10, A11) were fresh water-irrigated and have been used to grow both high value, salt sensitive crops (lettuce, corn, onions, garlic, tomato), as well as more salt tolerant crops (wheat, cotton, and alfalfa). Drainage water and tail water from these three fields was collected and applied to the fourth field (Area B) where salt tolerant crops are grown. Crops grown in this field included salt tolerant agronomic crops (canola, cotton, wheat), but now forage crops (‘Jose’ tall wheatgrass and creeping wild rye var. ‘Rio’) comprise most of the area due to the expansion of animal production in the local area. Drainage water collected under area B and tail water were then sequentially applied to a small area containing various salt tolerant forages (Area C, 5.2 ha) and to a halophyte area (Area D, 2 ha) prior to discharge into an evaporation area.

Water applied to each of the areas was measured using water meters. Groundwater observation wells were installed in the reuse area (B) to monitor ground water quality and groundwater response to irrigation. Ground water sampling was done approximately monthly during this experiment and depth was measured continuously using pressure transducers. The electrical conductivity (EC) of the irrigation water applied to the salt sensitive crops was approximately 0.4 dS/m and EC of the drainage water applied to the first reuse area was approximately 10-14 dS/m. Climatic data were measured using the CIMIS weather station located approximately 15 km from the field site.

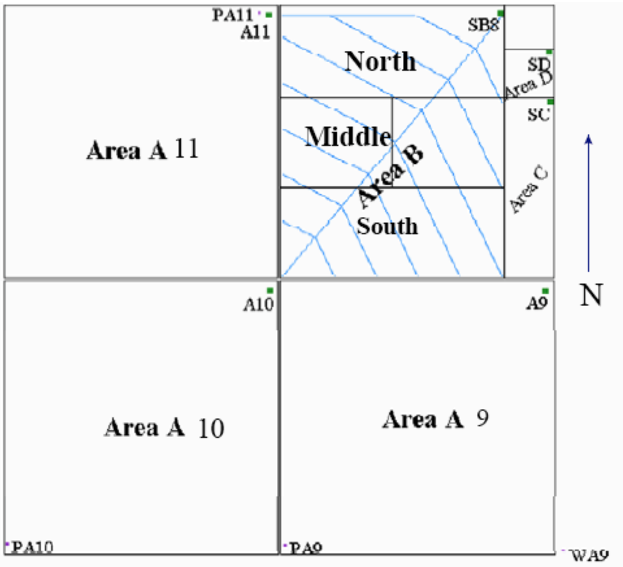

Figure 1 Layout of IFDM system at Red Rock Ranch in the San Joaquin Valley of California

Results and discussion

The IFDM installation was begun approximately 10 years ago and has been fully operational for approximately the last 5 years. During this time the fields labeled A have been reclaimed and there has been reclamation in the area B. Reclamation in area B began in the south section of the field and has progressed north such that the western half of the middle section has also been reclaimed, leaving only the northern and eastern half of the middle section under saline irrigation, an area less than 24.3 ha.

The average electrical conductivity data for the groundwater samples taken from each of the observation wells and from the drainage sumps in each field of the IFDM system are given in figure 2. There are several trends worth noting. First, the salinity of the groundwater in the north and middle sections of area B (GW-N, GW-M) was significantly higher than the groundwater in the south section of area B. The ground water quality in the south section (GW-S) was approximately the same EC as the drainage water from each of the other fields SA-9, SA-11, Note that the drainage water EC at the field B sump (SB8) was significantly lower than the ground water EC from the north and south areas of section B. It is also of note to compare the EC of the drainage water discharging from the salt sensitive areas A and drainage water areas B and C, the first and second reuse areas. The increase in salinity, going from areas A to area B is roughly 2 dS/m, while there is no difference in the EC between the ground water and the drainage water under reuse areas B (SB8) and C (SC). For salinity to increase only 2 dS/m in the deep percolate in the first reuse the leaching fraction would be approximately 80%, which is not probable. Having the same EC values in the drainage water under areas B and C suggests that there is no concentrating effect due to crop water use. This lack of apparent concentration due to crop water use is explained by the physical situation existing at the site.

There is a significant store of salt in the soil profile which is mined by subsurface flow to the drains, which tends to mask the concentrating effect of the crop water use. This is in contradiction to what was observed in the sites in Australia where measurable increases in concentration of the drainage flow were found as a result of successive reuse of water (Blackwell et al. 2004).

Using the ground water data from the north and middle sections of area B and the EC data from SA11 which is the drainage water from field A11 and A9 and A10, the computed leaching fraction is approximately 40% but more importantly there appears to be a concentration of the applied water.

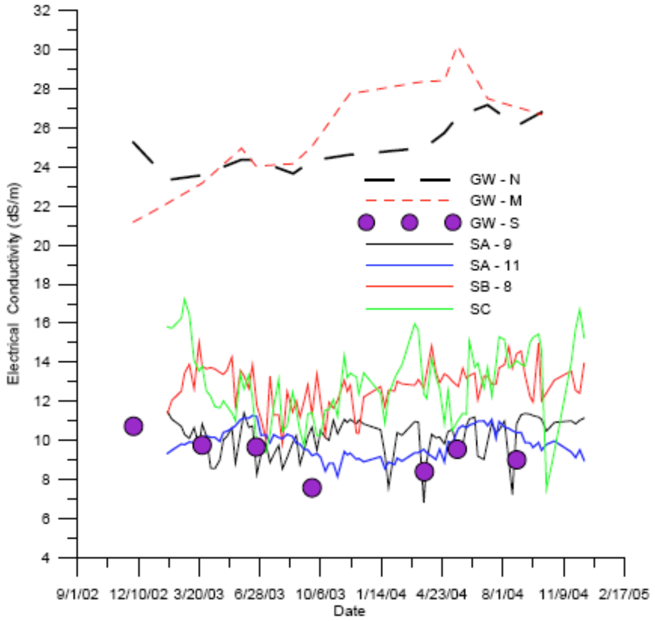

Figure 2 **Electrical conductivity of shallow ground in area B north (N), middle (M), and south (S) sections and the drainage water from each field in the IFDM system**

An annual water balance was calculated for the system using applied irrigation water, rainfall and measured drainage flow from each area. The data were summarized over a two-year period and used to determine the total applied water, and the volume of water discharged for disposal by evaporation. The data show that approximately 5050 ML of water were applied to 195 ha and the ultimate drainage value was 35 ML which is 0.7% of the total water applied. Individual water balances developed for each of the irrigation areas demonstrated that in area A11 there was approximately a 10% leaching fraction, while in areas combined A10 and A9 the leaching fraction was approximately 6%. The applied water data and drainage data from area B, which is the first reuse area, indicated approximately a 20% leaching fraction. The total salt load applied to the north of area B was approximately 290 t/ha over a two-year period.

During the last five years of the project, there has been a progression from surface irrigation to sprinkler irrigation to drip irrigation on those fields being used for high-value crops. As a result, there has been a significant increase in the irrigation efficiency, which has resulted in decreased deep percolation losses. As such, there has been a decrease in the area required for reuse of drainage water that has increased the production area for higher value crops. The estimated total area used for evaporation and reuse of drainage water is approximately 6% of the total project area. This compares to a rule of thumb previously used in the Central Valley that indicated approximately 10% of the drained area served was needed for evaporation ponds. It is conceivable that increased irrigation efficiencies will further significantly reduce the total area required for reuse and evaporation

One potential problem with these systems is the collection of lateral groundwater flow from adjacent properties that would increase the total area required for disposal. The water balance undertaken for this site indicated that this is probably not occurring here. The drainage systems were installed at a relatively shallow depth (1.8 m) in an attempt to ensure that regional groundwater flow was not intercepted and apparently this was successful. In addition to the drain line depth, Eucalyptus trees were planted on the up gradient side of this site to attempt to intercept any lateral flow.

The final evaporation system for the drainage water currently being used in this project consists of a rock medium underlain with an impermeable barrier with the drainage water being sprayed on it. Any water percolating through the rock is collected and recycled back through the system. This is required, because open water surfaces are not permitted by California law due to potentially high levels of selenium in the drainage water which is toxic.

The one issue remaining with this type of system is the final disposal of accumulated salt since the drainage water in this area contains toxic trace elements and other impurities. There have not been any viable alternatives developed for their ultimate disposal. This limits the long-term sustainability of an IFDM system.

Conclusions

A long-term study of sequential biological concentration in California demonstrated that this system does work in reducing the total volume of drainage water for disposal. Due to the geologic conditions in this area, the concept of biologic concentration of salts is not demonstrated. Improving irrigation efficiency and modifications to drainage system designs have made it possible to significantly reduce the total area required for groundwater disposal to less than 6% of the area are being served. Sustainability of this type system will require identification of final salt disposal options.

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